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Applicant: Mogens Rysholt Poulsen
Nordre Frihavnsgade 57, 4.th
DK-2100 København Ø

Jochen F. Kuhmann
Uglevej 9, 4.tv
DK-2400 København NV

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Hybrid Integration of Active and Passive Optical Components on a Si-Board

This invention relates to an apparatus and a method for assembling active and passive photonic components on a silicon board. The invention relates in particular to an apparatus and a method aligning the photonic components during the assembling procedure.

Light signal components for broadband communication systems have been driven towards a state of higher complexity, increased functionality and system reliability. This state has been reached by combining two technologies; optical waveguides (fibres and planar structures) and integrated photonic components (light signal transceivers such as semiconductor lasers, LED's and photodiodes).

The combination traditionally takes place by positioning an optical fibre relative to a photonic component or vice versa, and fasten these in a housing. This procedure typically makes use of apertures or lenses to couple the light into the waveguide. The photonic component positioning demands a costly and time consuming active alignment procedure, using photodiodes to optimise the amount of transmitted light.

It would be a great advantage if the different photonic components could be attached directly to the substrate on which the waveguides and integrated components exist. If this attachment could include alignment and fastening of the components in a simple "clip-on" procedure, large-scale fabrication would be more cost effective. This integration of separate components onto a substrate is called hybrid integration. A typical application of hybrid integrated photonic components is shown in Fig. 1 where a pump laser device 2 is attached onto a substrate 10. The substrate also holds a waveguide 4 leading the light from the laser to other parts of an integrated optical circuit. The hybrid integration allows the light from the pump laser to be coupled directly into the waveguide leading to the other integrated components, without increasing the complexity of the assembly.

A question of essential significance has arisen during these efforts; how does one obtain a long-term mechanical stability between the photonic component and the waveguide on the structure, and how can the active alignment procedure be avoided? This question has created a technical challenge for the fiberoptics components industry, to realise robust fiberoptic modules, which couples the signals of the photonic component to the fibre or

waveguide. The necessary coupling tolerance is in the submicron region and the fixation needs a mechanical stability of less than +/- 0.1μm under all possible operation- and storage- conditions.

In the prior art there are several attempts to find a procedure for fastening photonic components such as lasers to a substrate holding a waveguide, while simultaneously performing a passive alignment of the laser relative to the waveguide.

Methods using highly accurate Flip-Chip Bonding machines have been developed. These make use of optical detection of fiducials and marks on the substrate relative to which the photonic component is oriented and fastened. This production is however very expensive and have a precision of approximately 1μm.

Self-aligned bonding which make use of micromachined V-grooves for fibre fixation and the surface tension forces of the molten solder material, has been proposed and taken up by research facilities around the world. The method has been proven to reach the required tolerances. Nevertheless, the needed accuracy, which is within 1 μm, requires extremely well controlled process tolerances, which will be costly to develop.

One of the alignment concepts that make use of etched alignment structures and surface tension forces of the molten solder material, is presented in US 5,656,507. Here the silicon substrate is prepared with a waveguide, two alignment stops, a V-shaped groove and a trench with an L-shaped metal pad in the bottom. The bottom of the laser holds a ridge and an L-shaped metal pad with a solder bump so as to fit the V-shaped groove and the L-shaped metal pad on the silicon substrate. The principle is that when the laser is placed on the silicon substrate with the ridge inserted in the groove and an edge abutted to the alignment stops, the two L-shaped metal pads are slightly displaced though connected by the solder bump. When the solder is melted, it will draw the laser into alignment with the waveguide through surface tension forces.

Many companies have shifted their focus to alignment concepts which require highly accurate pick and place machines in conjunction with alignment fiducials on the assembled parts (see H.L. Althaus et. al., "*Microsystems and Waferprocesses for Volumeproduction of Highly Reliable Fibre Optic Components for Telecom and Datacom Applications*", 47th ECTC Conf., San Jose, CA, 1997, pp. 7-15). These concepts require large investments

that only pay off for high volume applications. Parallel to that, an increasing number of publications emerged proposing a concept which makes use of dry- or wet-etched alignment structures, e.g. D. A. Ackerman (US 5,023,881), J. Gates et al. (*"Hybrid Integrated Silicon Optical Bench Planar Lightguide Circuits"*, 48th ECTC Conf., Seattle, WA, 1998, pp. 551-559) and S. A. Merrit (*"A Rapid Flip-Chip Bonding Method for Semiconductor Laser Diode Arrays"*, 48th ECTC Conf., Seattle, WA, 1998, pp. 775-779).

US 5,023,881 covers the use of pedestals which initially forms a gap in-between the laser and the substrate. The vertical alignment is achieved by placing the laser on top of two pedestals, and the precision relies on the thickness of numerous individual layers. The specific alignment step consists of a cold welding for tacking the laser during the subsequent soldering. The horizontal alignment is not addressed in this patent and needs to be realised presumably by micromanipulation ("in a predetermined way").

Another alignment concept, which makes use of etched alignment structures, is presented in US 5,721,797. US 5,721,797 presents a method for aligning a laser relative to a fibre or a waveguide comprising several alignment stops and one or more solder bumps. Here, only the method relating to the waveguide is of interest. First, a trench is etched into the silicon substrate, and a cladding material is filled into a first part of the trench. Second, a solder bump is deposited into the second part of the trench. The waveguide and the alignment stops are now positioned on top of the silicon substrate so that the waveguide is lying on top of the cladding, filling part of the trench.

When the laser is now applied on top of the solder bump and slithered towards the end of the waveguide, the alignment stops are positioned so as to align the laser and the waveguide horizontally and to define the distance from the laser output port to the waveguide end. It should be noted that it is the sides of the laser, which abut the alignment stops. Since the laser component is cleaved or cut from a larger structure, some roughness of these surfaces is to be expected. Applying heat to the assembly, thereby melting the solder bump carries out the vertical alignment via surface tension. By doing this, the laser will in one step be positioned on the top surface of the silicon substrate and be soldered to the bottom of the trench.

Often, hybrid integration apparatuses are not compatible with the diversity of photonic devices from different manufacturers. Most of the prior art implies certain dimensions and

features of the devices in order to perform the hybrid integration, so if the device is changed, so must the assembly structure. The situation in a production optically integrated circuits is however that the photonic devices changes and therefore expensive and time consuming adjustments have to be made to the assembly structures.

It is a disadvantage of the existing alignment concepts that the alignment step is performed while fastening the photonic component to the substrate. Thus, the alignment is "non-reversible" and can not be inspected before fastening has taken place.

It is a further disadvantage of the existing alignment concepts that a precise horizontal alignment is not provided since it relies on the precision to which several alignment structures are deposited in several independent steps, or to the accuracy to which a cleaved surface abut an alignment structure.

It is a still further disadvantage of the existing alignment concepts that the vertical alignment relies on the thickness of several individual material layers.

It is a still further disadvantage of the existing alignment concepts that there is not disclosed any methods for a precise adjustment of the vertical alignment if the active region to be aligned resides at a given height inside the laser.

It is an object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly in which alignment can be realised before fastening.

It is another object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly in which reworking in case of a malfunctioning photonic components is possible, since the malfunctioning component can be detached by heating the structure, and replaced by a new component.

It is still another object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly, which implies only a minimum of "add-on" features to the photonic device, and does not require certain dimensions of the photonic device.

It is still another object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly where no processing, such as etching or polishing, of the often fragile photonic device is needed.

It is still another object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly where the horizontal alignment relies on a single mask step in a photolithographic process.

It is still another object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly where the vertical alignment relies on the positioning of aligned components on what are essentially different parts of the same surface.

It is still another object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly where no accurate cleaving is needed since no cleaved surfaces abut during alignment.

It is still another object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly of photonic components, which is compact and thereby easy to pack and stack.

It is still another object of the present invention to provide an apparatus and a method for self-aligned hybrid assembly of an array of photonic devices on a substrate.

The above-mentioned objects are complied with by providing in a first aspect of the present invention an assembly structure comprising:

- a substrate holding a bottom cladding layer, said bottom cladding layer comprising a first and a second part, wherein each part comprises a top and a bottom surface separated by a distance d,

- an optical waveguide comprising a top and a bottom surface, said optical waveguide further comprising a light receiving input end, the bottom surface of said optical waveguide being positioned at a distance larger than or equal to d above the bottom surface of the bottom cladding layer, and

- one or more first alignment features being formed in the second part of the bottom cladding layer, said first alignment features comprising a top surface.

The top surface of the first alignment features is essentially in the same plane as the top surface of the first part of the bottom cladding layer. In order to confine light within the optical waveguide an additional material is provided to embed the waveguide core.

The assembly may further comprise a set of electrical contact pads suitable for providing electric energy to e.g. a light source, such as a semiconductor laser or a light emitting diode (LED).

Preferably, the bottom surface of the optical waveguide is positioned on the top surface of the bottom cladding layer at a distance substantially equal to d, where d is measured from the bottom surface of the bottom cladding layer.

The assembly structure according to the first aspect of the present invention may further comprise

- an optoelectronic device comprising an active part and a light output port, said output port being optically aligned with the waveguide input end by having the optoelectronic device arranged on top of the first alignment features to thereby obtain vertical alignment.

In order to horizontally align the light receiving input end of the optical waveguide with the light output port of the optoelectronic device, the assembly structure may further comprise one or more second alignment features abutting the one or more of the first alignment features of the second part of the bottom cladding layer.

For example, the optoelectronic device may be a light source comprising a light output port, an active part and one or more second alignment features being adapted to abut one or more of the first alignment features of the second part of the bottom cladding layer so as to align the light receiving input end of the optical waveguide with the light output port of the light source.

Etching may be applied to fabricate the assembly structure. In order to control the etching process an etch stop layer may be provided at some stage during the fabrication process on top of the first alignment features. In an embodiment according to the invention the etch stop layer is maintained on top of the first alignment features thereby arranged below the optoelectronic device.

It is preferred that during the formation of the assembly structure, the positioning of the optical waveguide and the first alignment features is defined using a single mask. The reason for this being that for every mask being involved in the fabrication process an uncertainty is introduced in the positioning of one mask relative to another mask.

At least one of the first alignment features may comprise an outwardly tapered part. Preferably, two of the first alignment features comprise an outwardly tapered part, and the alignment features may be separated by a distance larger than the width of the active part of the optoelectronic device.

The second alignment features may comprise solder stripes arranged on the bottom of the optoelectronic device so as to at least partly engage outer side walls of the first alignment features. Preferably, at least two solder stripes are arranged on the bottom of the optoelectronic device. In order to provide electrical power to the optoelectronic device the optoelectronic device may be soldered to contact pads formed on exposed parts of the substrate.

As already mentioned, the optoelectronic device may comprise a variety of light sources, such as a laser or an LED. The laser may be a laser diode, such as a semiconductor laser diode.

In a second aspect, the present invention relates to a method of forming an assembly structure for assembling an optoelectronic device and an optical waveguide, said optical waveguide comprising a light input end for receiving light emitted from an output port of the optoelectronic device, said method comprising the steps of:

- providing a bottom cladding layer on top of a substrate, said bottom cladding layer comprising a first and a second part, wherein each part comprises a top and a bottom surface separated by a distance d,

- providing a core layer on top of at least part of the bottom cladding layer,

- forming the optical waveguide in the core layer, said optical waveguide thereby extending in a plane and at a distance larger than or equal to d from the bottom surface of the first part of the bottom cladding layer, and

- forming one or more first alignment features in the second part of the bottom cladding layer so that at least one top surface of the first alignment features is in essentially the same plane as the top surface of the first part of the bottom cladding layer.

The method according to the second aspect of the present invention may further comprise the step of:

- aligning the output port of the optoelectronic device with the light input end of optical waveguide, said alignment comprising the step of arranging the optoelectronic device on top of the one or more alignment features so as to obtain vertical alignment.

The optical waveguide may extend on the top surface of the bottom cladding layer at a distance substantially equal to d above the bottom surface of the bottom cladding layer.

As mentioned in relation with the first aspect of the present invention the optoelectronic device may further comprise one or more second alignment features so as to horizontally align the light receiving input end of the optical waveguide with the light output port of the optoelectronic device. Again, it is preferred that the positioning of the optical waveguide and the first alignment features are defined using a single mask.

The method according to the second aspect of the present invention may even further comprise the step of providing an etch stop layer on at least part of the second part of the bottom cladding layer prior to deposition of the core layer, said core layer extending on both the first and the second part of the bottom cladding layer thereby covering at least part of the etch stop layer.

The formation of the optical waveguide and the first alignment features preferably comprises the steps of:

a) defining the horizontal configuration of the optical waveguide and the first alignment features in the core layer by a single mask process,

b) partially removing the core layer thereby forming the optical waveguide and defining the first alignment features in the core layer,

c) removing that part of the etch stop layer not being covered by the core layer,

d) providing a top cladding layer so as to at least partly cover the optical waveguide and optionally the one or more alignment features formed in the core layer, and

e) removing the top cladding layer, the core layer and at least part of the second part of the bottom cladding layer to thereby form the first alignment features in the bottom cladding layer.

The etch stop layer defining the one or more alignment features formed in the bottom cladding layer may optionally be totally removed or only partly removed. If the etch stop layer is only partly removed the remaining layer may be used to adjust the height of the optoelectronic device relative to the optical waveguide.

The removing in step e) may comprise etching the second part of the bottom cladding layer so as to expose that part of the substrate not being covered by the first alignment features. Preferably, the etching process involves an anisotropic etch, such as reactive ion etching.

Preferably, two of the first alignment features comprise an outwardly tapered part, said two alignment features being separated by a distance larger than or equal to the width of the active part of the optoelectronic device. The one or more second alignment features are arranged on the bottom of the optoelectronic device so as to at least partly engage outer side walls of the first alignment features while aligning the optoelectronic device. The second alignment features may comprise solder stripes so as to electrically connect the optoelectronic device to e.g. a power supply. Preferably, at least two solder stripes are arranged on the bottom of the optoelectronic device.

The method according to the second aspect of the present invention may further comprise soldering the optoelectronic device to one or more electrical contact pads formed beside the alignment features on exposed parts of the substrate. Preferably, soldering is performed by applying heating the solder stripes above a certain melting temperature. If e.g. a bad connection has been established during soldering, or the optoelectronic device turns out to be malfunctioning, the device may be removed by heating the assembly and thereafter replaced with new device.

The optoelectronic device may comprise any kind of light source, such as a laser diode or an LED. The laser diode may be a semiconductor laser diode.

In a third aspect, the present invention relates to an assembly structure comprising:

- a substrate having one or more first alignment features disposed thereon, and

- a first photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said first photonic device being positioned on top of a first group of the first alignment features, wherein

the second alignment features of the first photonic device is arranged so as to at least partly engage outer side walls of the first group of the first alignment features.

The assembly structure according to the third aspect of the present invention may further comprise:

- a second photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said second photonic device being positioned on top of a second group of the first alignment features, wherein

the second alignment features of the second photonic device is arranged so as to at least partly engage outer side walls of the second group of the first alignment features.

The light input or output port of the first and/or second photonic device may have a predetermined orientation and height with respect to the substrate.

In one example, the first photonic device comprises a light input port and the second photonic device comprises a light output port. The photonic devices are positioned so as to align the light input port of the first photonic device with the light output port of the second photonic device. This example could be the situation where a light source, such as a semiconductor laser or an LED, is aligned with a light receiving input end of an optical waveguide, such as an optical fibre or a planar waveguide, so as to couple electromagnetic radiation from the optoelectronic device to the optical waveguide.

In another example, the first photonic device and the second photonic device both have a light output port, and the photonic devices are positioned so as to align the two light output ports along two parallel optical axes. This example could be the situation where two laser diodes, such as two semiconductor laser diodes, are to be aligned relative to each other so as to e.g. emit two substantially parallel beams of electromagnetic radiation.

The second alignment features of the first and/or second photonic device may comprise one or more solder stripes. Preferably, at least two solder stripes are arranged on the bottom of a photonic device.

Preferably, at least one of the first or second group of the first alignment features comprises a tapered part so as to ensure horizontal alignment of two photonic devices. The height of the first alignment features may be adjusted so as to ensure the vertical alignment.

A photonic device may comprise an active waveguide component, such as an optical amplifier, such as a fibre amplifier.

In a fourth aspect, the present invention relates to a method of forming an assembly structure, said method comprising the steps of:

- providing a substrate having one or more first alignment features disposed thereon,

- providing a first photonic device, said first photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said first photonic device being positioned on top of a first group of the first alignment features, wherein

the second alignment features of the first photonic device are arranged so as to at least partly engage outer side walls of the first group of the first alignment features.

The method may further comprise the step of:

- providing a second photonic device, said second photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said second photonic device being positioned on top of a second group of the first alignment features, wherein

the second alignment features of the second photonic device are arranged so as to at least partly engage outer side walls of the second group of the first alignment features.

For most applications the light input or output port of a photonic device has a predetermined orientation and height with respect to the substrate.

Different schemes may arise. The first photonic device may have a light input port whereas the second photonic device may have a light output port. The situation may also be that the first photonic device and the second photonic device may both have a light output port. In both cases the first and second photonic devices are positioned relative to each other so as to align the input/outputs so that electromagnetic radiation propagates substantially along at least one predetermined optical axis.

The second alignment features of the first and/or second photonic device may comprise one or more solder stripes. Preferably, at least two solder stripes are arranged on the bottom of each photonic device.

Preferably, at least one of the first or second group of the first alignment features comprises a tapered part, where the height of the first alignment features may be adjusted so as to obtain vertical alignment. The engagement of the first alignment features and the second alignment features ensures horizontal alignment. Thus both vertical and horizontal alignment can be achieved prior to fixation of a photonic device.

A photonic device may comprise a passive optical component, such as an optical waveguide, such as an optical fibre or a planar waveguide. A photonic device may also comprise an optoelectronic device, such as a laser diode or an LED. Finally, a photonic device may comprise an active waveguide component, such as an optical amplifier, such as a fibre amplifier. In order to achieve amplification, the active waveguide may comprise rare-earth materials, such as erbium.

In a fifth aspect, the present invention relates to a method of aligning a plurality of photonic devices, said method comprising the steps of:

- providing a substrate having a plurality of groups of first alignment features disposed thereon,

- providing a first photonic device, said first photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said first photonic device being positioned on top of a first group of the first alignment features,

- providing a second photonic device, said second photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said second photonic device being positioned on top of a second group of the first alignment features so as to align the light input or output port of the first photonic device with the light input or output port of the second photonic device, wherein

the second alignment features of the first and second photonic device are arranged so as to at least partly engage outer side walls of the first and second group of the first alignment features.

The light input or output ports of the photonic devices may have predetermined orientation(s) and height(s) with respect to the substrate.

As previously mentioned, the first photonic device may have a light input port and the second photonic device may have a light output port. The photonic devices may be positioned so as to align the light input port of the first photonic device with the light output port of the second photonic device so as to couple light from the second photonic device to the first photonic device.

Alternatively, the first photonic device and the second photonic device both have a light output port. Here the photonic devices are positioned so as to align the two light output ports along two parallel optical axes. Such an alignment could e.g. be used to form an array of light sources each emitting electromagnetic radiation.

Again, the second alignment features of the photonic devices may comprise one or more solder stripes so as to electrically connect each of the photonic devices to e.g. a power supply. Preferably, at least two solder stripes are arranged on the bottom of each photonic device.

At least one alignment feature of the plurality of first alignment features may comprise a tapered part so that engagement of the first alignment features and the second alignment features ensures horizontal alignment. The height of the first alignment features may be adjusted so as to obtain vertical alignment.

As previously mentioned the first and second photonic devices may comprise passive optical components, such as optical waveguides, such as optical fibres or planar waveguides. The first and second photonic devices may also comprise optoelectronic devices, such as laser diodes or LEDs. Finally the first and second photonic device may comprise active waveguide components, such as optical amplifiers, such as fibre amplifiers.

In the following, the present invention will be described in further detail with references to the figures listed below.

Fig. 1 shows typically optical chip including a hybrid integrated pump laser and a waveguide.

Fig. 2 shows the first step of fabricating the assembly structure, in which a bottom cladding is deposited on a silicon substrate.

Fig. 3 shows a polysilicon etch stop applied on part of the bottom cladding.

Fig. 4 shows a layer of core glass applied on the structure of Fig. 3.

Fig. 5 shows the structure of Fig. 4 after an etching step defining the waveguide and alignment taper templates.

Fig. 6 shows the structure of Fig. 5 after removal of the accessible polysilicon etch stop.

Fig. 7 shows several top cladding layers applied on the structure of Fig. 6.

Fig. 8 shows the structure of Fig. 7 after removal by etching of the front part of the top cladding and alignment taper templates.

Fig. 9 shows continued etching of the structure of Fig. 8 completing the alignment tapers.

Fig. 10 shows metal pads serving as laser electrodes and thermal paths applied on the structure of Fig. 9.

Fig. 11 shows a photonic device to be applied on top of the structure of Fig. 10.

Fig. 12 shows the aligned assembled structure while melting the solder stripes for fastening.

Fig. 13 shows an exploded view of the structure of Fig. 12 revealing the melted solder stripes.

Fig. 14 is a front view of the aligned assembled structure.

Fig. 15 is a close up on Fig. 14 showing the solder stripes, the alignment tapers and the metal pads.

Fig. 16 shows the same as Fig. 15 after melting the solder stripes.

Fig. 17 A and B shows arrays of alignment tapers with photonic devices.

Fig. 18 shows an array of alignment tapers with photonic devices on a substrate also holding other features.

The fabrication of the structures to be applied in hybrid integration procedures according to the present invention makes use of standard semiconductor technology. The invention can be realised in a plurality of embodiments of which only a representative selection is described here.

In a first embodiment the present invention relates to an assembly structure for performing hybridisation of an opto-electronic device onto a substrate holding a waveguide. An opto-electronic device can be a light emitting component such as a laser or a Light Emitting Diode (LED), or a light receiving component such as a photodiode. The hybrid integration

includes aligning the laser and the waveguide, and soldering the laser to the substrate securing a long term mechanical stability.

The description of this first embodiment also serves as a general description of the essential features involved in the present invention. Therefore not all steps and features included in this description are necessary in order for the invention to be realised, and the description should by no means be interpreted as limiting the scope of the invention. The composition of the assembly structure is best described by going through the stepwise manufacturing procedure with reference to Figures 2-13.

Fig. 2 shows the first step of fabricating the assembly structure, in which a bottom cladding layer 12 is deposited on a substrate 10. Preferably the substrate is composed of Silicon or other inorganic or organic substrate material; the bottom cladding layer is SiO_2 or other materials different from the core material to be deposited later. For practical purposes, the shown structure is nominally divided into a first part (in the back) and a second part (front). Fig. 3, an etch stop 14 is deposited on the second part of the bottom cladding. Possible etch stop materials are polysilicon, Boron doped polysilicon, metals or other inorganic materials. The next step consists of covering the structure with a deposited layer 16 of core glass, typically Germanium doped SiO_2 or other materials different from the cladding material, as shown in Fig. 4.

The depositing of cladding, etch stop and core glass layers can be carried out using Plasma Enhanced Chemical Vapour Deposition (PECVD), Low Pressure Chemical Vapour Deposition (LPCVD), or some vacuum deposition technique.

In Fig. 5, the formation of the waveguide core and alignment taper templates is carried out by a photolithographic process. First, the core glass layer is deposited onto the Si wafer. Next, the waveguide core and alignment taper templates are defined in the resist in the same photoresist processing step. The following RIE process removes the surrounding core glass material, leaving only the waveguide core 18 and the alignment taper templates 19. It is in this step that the essential horizontal alignment takes place. Since the waveguide core and the alignment taper templates are defined simultaneously in one mask step, the precision of the horizontal alignment is very precisely defined.
When working with optics in general, one often takes precautions to avoid back-scattering from surfaces such as input/output facets. The photolithography mask step described

above provides a simple measure for doing this in the present invention. By changing the illumination mask, the end of the waveguide core can be defined having an angled termination, hence any reflection from this surface will leave the system.

The polysilicon etch stop 14 not covered by the alignment taper templates are removed by wet- or dry etching, exposing the bottom cladding layer, see Fig. 6. The waveguide core has to be covered by a material for it to be able to guide electromagnetic radiation. There exist several choices of materials for embedding the waveguide core for it to be able to guide electromagnetic radiation. These can be defined using parameters such as refractive index. This is done in Fig. 7 where a top cladding layer 13, preferably similar to the bottom cladding layer, is deposited on the structure of Fig. 6. This cladding layer is removed again in an RIE process, but only from the second part of the structure, resulting in the structure in Fig. 8.

Completion of the etching process in Fig. 9 forms the alignment tapers 20 in the bottom cladding 12. Going from fig. 8 to 9, the etch stop mask 15 is also removed, revealing the top surface of the alignment tapers. It is important to note that the top surface of the bottom cladding layer 12 forms both the top surface of the alignment tapers and the surface on which the waveguide core 18 is deposited, that is, these are in the same plane. Thereby a very precise vertical alignment can be achieved by placing the object to be aligned on top of the alignment tapers.

A number of metal pads 22 are deposited on the exposed part of the silicon substrate 10 next to the alignment tapers 20 as shown in Fig. 10. These metal pads serve as "wet-able" regions for binding solder to the substrate in a later soldering (see e.g. Fig 16). After this soldering, the pads also serve as both thermal paths to the silicon substrate, and as electrical contacts for the opto-electronic device. The depositing can be carried out by electroplating, evaporation of metals onto the substrate or other vacuum deposition techniques.

As can be seen from Fig. 10, the whole assembly structure 30 is deposited on the substrate 10, and therefore no etching of trenches and groves in the silicon wafer is needed.

Referring now to Fig. 11, the opto-electronic device 24, a semiconductor laser in the preferred embodiment, is presented upside down showing the active region 28 to be aligned with the waveguide. The active region preferably resides so as to have its optical axis elevated above the bottom surface of the laser a distance equal to the distance of the optical axis of the waveguide above the bottom cladding layer. The exact position of the active region will be commented on later.

The laser 24 also holds one or more alignment features, here in the form of one or more solder stripes 26, which are deposited symmetrically on the bottom surface of the laser, with the active region 28 in the centre. One alignment step with the active region of the laser as reference will be needed in depositing the solder stripes, the accuracy of which is typically 0.2µm. Electroplated stripes of AuSn80 having very smooth surface structures is the preferable solder material in the present invention. Semiconductor lasers are often fragile and need a very gentle handling. Since the solder stripes are "add-on" there is no need for etching or polishing the laser, which is considered a major advantage.

To perform the alignment, the laser 24 is flipped according to the arrow in Fig. 11, for the solder stripes 26 to fit the alignment tapers 20. Thereafter the laser is slid towards the first part of the assembly structure, until the solder stripes abut the alignment tapers, as is achieved in Fig. 12. This last action is where the alignment with the waveguide takes place. The laser now rests upon the alignment tapers which ensures the vertical alignment (note the vertical position of the active region described above), and the solder stripes clamps the alignment tapers ensuring the horizontal alignment. Thus both vertical and horizontal alignment has been achieved, and due to the clamping of the solder stripes to the alignment tapers, they are held together firmly without being inseparable.

The horizontal alignment is only sensitive to the relative alignment of the solder stripes 26 to the active region 28. As long as the solder stripes are positioned symmetrically, any amendments of their separation will change the gap between the laser and the waveguide, but not result in lateral misalignment. In Fig. 12, the aligned and assembled structure is shown while melting the solder stripes for fastening the opto-electronic device. Fig. 13 shows an exploded view of the structure of Fig. 12 revealing the melted solder stripes.

The alignment and fastening procedure performed in Figures 11 to 13 are described in detail referring to Figures 14 to 16. Figure 14 shows a front view of Fig. 12 where it is seen

that the solder stripes 26 position the active region 28 precisely between the alignment tapers 20. From the close-up in Fig. 15 it is seen that the solder stripes contributes solely to the horizontal alignment, and therefore the height of the solder stripes is only restricted by the height of the alignment tapers. It is with noting that the alignment is performed prior to fastening of the opto-electronic device, hence any errors or inaccuracies obstructing a perfect alignment can be detected, and the fastening rejected.

After alignment, the melting of the solder stripes 26 effected from Fig. 15 to 16 is carried out by heating the assembled structure. In Fig. 16, the solder bulges up, wets, and excess solder flows along the metal pads 22 to make both thermal and electrical contact to the silicon substrate 10. This contact enables power supply to the laser 24 and enhances its temperature stability since it is over a broad area. Making additional wire bonding to the laser will heat the assembly considerably, however, since the laser rests on top of the alignment tapers, softening of the solder does not present a problem.

In the description of the assembly structure above (Fig. 11), it was implied that the active region 28 was residing a certain height above the bottom surface of the laser 24. However, in specific opto-electronic devices, the region to be aligned with the waveguide resides some given height above the bottom surface, inside the device, not being equal to the height of the centre of the waveguide core. This will cause the region 28 to be either elevated or lowered relative to the waveguide centre, when the device is mounted.

Two embodiments of the present invention addresses this problem, a first applies where the active region is elevated relative to the waveguide core centre, and a second when it is lowered.

First embodiment: The waveguide core 18 can be elevated by depositing a second cladding layer prior to formation of the core layer (16 in Fig. 4) by vacuum deposition. Instead of resting on the top surface of the bottom cladding layer, the waveguide core 18 in Fig 5 now rests on the remaining part of the second cladding layer, resting on the bottom cladding layer 12. This will elevate the waveguide a distance equal to the thickness of the second cladding layer above the top surface of the bottom cladding layer. Referring now to Figure 9, the top surface of the alignment taper 20 will still be in the plane of the top surface of the bottom cladding layer 12. Since the thickness of the second cladding layer is

known, the top surface of the alignment tapers 20 is still well defined relative to the waveguide.

Second embodiment: The mounted device can be elevated relative to the waveguide by increasing the height of the alignment tapers. This is easily done by leaving all or part of the etch stop mask 15 in Fig. 8 otherwise removed after the etching of the cladding layers. Adjusting the original thickness of the etch stop layer allows the mounted device to be elevated a given height relative to the waveguide.

These two well-defined height adjustments using only the thickness of a single layer, permits a precise vertical alignment of the waveguide and the opto-electronic device, also when the region to be aligned resides some given height above the bottom surface, i.e. inside the opto-electronic device.

Alternative embodiments of the present invention exist when the object is to align several photonic devices either relative to each other, or relative to another object. Here, a photonic device refers to both opto-electronic components and other optical devices such as amplifying waveguides. In this case there may not be a waveguide in the assembly structure. The alignment tapers will be positioned in either of two ways, as described in Figures 17 and 18:

1. a number of alignment tapers 20 defined in one mask step, and formed in the same cladding layer with the top surfaces of all tapers being in the same plane (Fig. 17 A and B), or
2. a number of alignment tapers 20 defined and formed as in 1, but the one mask step including the definition of another feature 32 on the substrate (Fig. 18). This other feature could be a photonic device or another alignment feature.

The embodiment addressed in Fig 17A applies where two or more photonic devices are hybrid integrated after each other in a line. Contrary to the waveguide in the assembly structure described above, none of the photonic devices to be aligned are formed on the substrate. The two or more photonic devices 25 have light input/output ports, which are to be internally aligned in order to acquire an efficient light coupling between them.

In the embodiments shown in Figures 17B and 18 the alignment tapers and the attached device(s), are oriented relative to an imaginary frame of reference. The alignment will be both an alignment and a three-dimensional positioning with a high precision in especially the transverse directions relative to the alignment tapers.

These two embodiments can be utilised when e.g. an array of photonic devices is desired. The array of alignment tapers can be formed as described in 1 above (Fig 17B), on a separate substrate 11, which thereby holds an array of internally aligned devices 25. Or, as described in 2 (Fig. 18), the array can be formed and internally aligned on a substrate holding other features such as 32, the array being aligned relative to these features also. The procedure of forming the alignment tapers and attaching the device are essentially the same as in the embodiment described in with reference to Figures 2 through 13.

The principles of the present invention provide a precise method for positioning and aligning devices and structures at different positions on a substrate. Several 3-dimensional positioning and alignment arrangements of photonic devices are feasible by combining any of the above described embodiments. Also, hybrid integration, involving alignment and positioning, is of interest for numerous classes of photonic devices, which further extends the scope of the present invention.

CLAIMS

1. An assembly structure comprising:

- a substrate holding a bottom cladding layer, said bottom cladding layer comprising a first and a second part, wherein each part comprises a top and a bottom surface separated by a distance d,

- an optical waveguide comprising a top and a bottom surface, said optical waveguide further comprising a light receiving input end, the bottom surface of said optical waveguide being positioned at a distance larger than or equal to d above the bottom surface of the bottom cladding layer,

- one or more first alignment features being formed in the second part of the bottom cladding layer, said first alignment features comprising a top surface which is essentially in the same plane as the top surface of the first part of the bottom cladding layer, and

- a top cladding layer surrounding the optical waveguide so as to guide electromagnetic radiation within the optical waveguide.

2. An assembly structure according to claim 1 further comprising a set of electrical contact pads.

3. An assembly structure according to claim 1 or 2, wherein the bottom surface of the optical waveguide is positioned on the top surface of the bottom cladding layer at a distance substantially equal to d above the bottom surface of the bottom cladding layer.

4. An assembly structure according to any of the preceding claims, further comprising

- an optoelectronic device comprising an active part and a light output port, said output port being optically aligned with the waveguide input by having the

optoelectronic device arranged on top of the first alignment features to thereby obtain vertical alignment.

5. An assembly structure according to claim 4, wherein the optoelectronic device further comprises one or more second alignment features, and wherein one or more of said second alignment features abut one or more of the first alignment features of the second part of the bottom cladding layer so as to horizontally align the light receiving input end of the optical waveguide with the light output port of the optoelectronic device.

6. An assembly structure according to any of claims 1-3 further comprising

- an optoelectronic device comprising a light output port, an active part and one or more second alignment features, wherein one or more of the second alignment features abut one or more of the first alignment features of the second part of the bottom cladding layer so as to align the light receiving input end of the optical waveguide with the light output port of the optoelectronic device.

7. An assembly structure according to any of claims 4-6, wherein an etch stop layer is provided on top of the first alignment features below the optoelectronic device.

8. An assembly structure according to any of claims 1-7, wherein, during the formation of said assembly, the positioning of the optical waveguide and the first alignment features are defined using a single mask.

9. An assembly structure according to any of claims 1-8, wherein at least one of the first alignment features comprises an outwardly tapered part.

10. An assembly structure according to claim 9, wherein two of the first alignment features comprise an outwardly tapered part, said two alignment features being separated by a distance larger than the width of the active part of the optoelectronic device.

11. An assembly structure according to any of claims 5-10, wherein the second alignment features comprise solder stripes arranged on the bottom of the optoelectronic device so as to at least partly engage outer side walls of the first alignment features.

12. An assembly structure according to claim 11, wherein at least two solder stripes are arranged on the bottom of the optoelectronic device.

13. An assembly structure according to any of claims 4-12, wherein the optoelectronic device is soldered to contact pads formed on exposed parts of the substrate.

14. An assembly structure according to any of claims 4-13, wherein the optoelectronic device comprises a laser diode, such as a semiconductor laser diode.

15. An assembly structure according to any of claims 4-13, wherein the optoelectronic device comprises an LED.

16. A method of forming an assembly structure for assembling an optoelectronic device and an optical waveguide, said optical waveguide comprising a light input end for receiving light emitted from an output port of the optoelectronic device, said method comprising the steps of:

- providing a bottom cladding layer on top of a substrate, said bottom cladding layer comprising a first and a second part, wherein each part comprises a top and a bottom surface separated by a distance d,

- providing a core layer on top of at least part of the bottom cladding layer,

- forming the optical waveguide in the core layer, said optical waveguide thereby extending in a plane and at a distance larger than or equal to d from the bottom surface of the first part of the bottom cladding layer, and

- forming one or more first alignment features in the second part of the bottom cladding layer so that at least one top surface of the first alignment features is in essentially the same plane as the top surface of the first part of the bottom cladding layer.

17. A method according to claim 16, further comprising

- aligning the output port of the optoelectronic device with the light input end of optical waveguide, said alignment comprising the step of arranging the optoelectronic device on top of the one or more alignment features so as to obtain vertical alignment.

18. A method according to claim 16 or 17, wherein the optical waveguide extends on the top surface of the bottom cladding layer at a distance substantially equal to d above the bottom surface of the bottom cladding layer.

19. A method according to claim 17 or 18, wherein the optoelectronic device further comprises one or more second alignment features, and wherein one or more of said second alignment features abut one or more of the first alignment features of the second part of the bottom cladding layer so as to horizontally align the light receiving input end of the optical waveguide with the light output port of the optoelectronic device.

20. A method according to any of claims16-19, wherein the positioning of the optical waveguide and the first alignment features is defined using a single mask.

21. A method according to any of the claims 17-20, wherein an etch stop layer is provided on top of the first alignment features below the optoelectronic device.

22. A method according to any of claims 16-21, wherein

- an etch stop layer is provided on at least part of the second part of the bottom cladding layer prior to deposition of the core layer, said core layer extending on

both the first and the second part of the bottom cladding layer thereby covering at least part of the etch stop layer, and

the formation of the optical waveguide and the first alignment features comprises:

a) defining the horizontal configuration of the optical waveguide and the first alignment features in the core layer by a single mask process,

b) partially removing the core layer thereby forming the optical waveguide and defining the first alignment features in the core layer,

c) removing that part of the etch stop layer not being covered by the core layer,

d) providing a top cladding layer so as to at least partly cover the optical waveguide and optionally the one or more alignment features formed in the core layer, and

e) removing the top cladding layer, the core layer and at least part of the second part of the bottom cladding layer to thereby form the first alignment features in the bottom cladding layer.

23. A method according to claim 22 and any of claims 16-20, further comprising the step of:

- removing the etch stop layer defining the one or more alignment features formed in the bottom cladding layer.

24. A method according to claim 22, wherein the removing in step e) comprises etching the second part of the bottom cladding layer so as to expose that part of the substrate not being covered by the first alignment features.

25. A method according to any of claims 22-24, wherein step e) comprises etching by reactive ion etching.

26. A method according to any of claims 16-25, wherein at least one of the first alignment features comprises an outwardly tapered part.

27. A method according to claim 26, wherein two of the first alignment features comprise an outwardly tapered part, said two alignment features being separated by a distance larger than or equal to the width of the active part of the optoelectronic device.

28. A method according to any of claims 16-27, wherein one or more second alignment features are arranged on the bottom of the optoelectronic device so as to at least partly engage outer side walls of the first alignment features when aligning the optoelectronic device.

29. A method according to claim 28, wherein the second alignment features comprise solder stripes.

30. A method according to claim 29, wherein at least two solder stripes are arranged on the bottom of the optoelectronic device.

31. A method according to any of claims 17-30, further comprising soldering the optoelectronic device to one or more electrical contact pads formed beside the alignment features on exposed parts of the substrate.

32. A method according to any of claims 16-31, wherein the optoelectronic device comprises a laser diode, such as a semiconductor laser diode.

33. A method according to any of claims 16-31, wherein the optoelectronic device comprises an LED.

34. An assembly structure comprising:

- a substrate having one or more first alignment features disposed thereon, and

- a first photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said first photonic device being positioned on top of a first group of the first alignment features, wherein

the second alignment features of the first photonic device is arranged so as to at least partly engage outer side walls of the first group of the first alignment features.

35. An assembly structure according to claim 34, further comprising

- a second photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said second photonic device being positioned on top of a second group of the first alignment features, wherein

the second alignment features of the second photonic device is arranged so as to at least partly engage outer side walls of the second group of the first alignment features.

36. An assembly structure according to claim 34 or 35, wherein the light input or output port of a photonic device has a predetermined orientation and height with respect to the substrate.

37. An assembly structure according to claim 35 or 36, wherein the first photonic device comprises a light input port and the second photonic device comprises a light output port, and wherein the photonic devices are positioned so as to align the light input port of the first photonic device with the light output port of the second photonic device.

38. An assembly structure according to claim 35 or 36, wherein the first photonic device and the second photonic device both have a light output port, and the photonic devices are positioned so as to align the two light output ports along two parallel optical paths.

39. An assembly structure according to any of claims 34-38, wherein the second alignment features of the first and/or second photonic device comprise one or more solder stripes.

40. An assembly structure according to claim 39, wherein at least two solder stripes are arranged on the bottom of a photonic device.

41. An assembly structure according to any of claims 34-40, wherein at least one of the first or second group of the first alignment features comprises a tapered part.

42. An assembly structure according to any of claims 35-41, wherein the height of the first alignment features is adjusted so as to obtain vertical alignment.

43. An assembly structure according to any of claims 34-42, wherein a photonic device comprises a passive optical component, such as an optical waveguide, such as an optical fibre or a planar waveguide.

44. An assembly structure according to any of claims 34-43, wherein a photonic device comprises an optoelectronic device, such as a laser diode or an LED.

45. An assembly structure according to any of claims 34-44, wherein a photonic device comprises an active waveguide component, such as an optical amplifier, such as a fibre amplifier.

46. A method of forming an assembly structure, said method comprising the steps of:

- providing a substrate having one or more first alignment features disposed thereon,

- providing a first photonic device, said first photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said first photonic device being positioned on top of a first group of the first alignment features, wherein

the second alignment features of the first photonic device are arranged so as to at least partly engage outer side walls of the first group of the first alignment features.

47. A method according to claim 46, further comprising the step of:

- providing a second photonic device, said second photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said second photonic device being positioned on top of a second group of the first alignment features, wherein

the second alignment features of the second photonic device are arranged so as to at least partly engage outer side walls of the second group of the first alignment features.

48. A method according to claim 46 or 47, wherein the light input or output port of a photonic device has a predetermined orientation and height with respect to the substrate.

49. A method according to claim 47 or 48, wherein the first photonic device comprises a light input port and the second photonic device comprises a light output port, and the photonic devices are positioned so as to align the light input port of the first photonic device with the light output port of the second photonic device.

50. A method according to claim 47 or 48, wherein the first photonic device and the second photonic device both have a light output port, and wherein the photonic devices are positioned so as to align the two light output ports along two parallel optical paths.

51. A method according to any of claims 46-50, wherein the second alignment features of the first and/or second photonic device comprise one or more solder stripes.

52. A method according to claim 51, wherein at least two solder stripes are arranged on the bottom of a photonic device.

53. A method according to any of claims 46-53, wherein at least one of the first or second group of the first alignment features comprises a tapered part.

54. A method according to any of claims 46-53, wherein the height of the first alignment features is adjusted so as to obtain vertical alignment.

55. A method according to any of claims 46-54, wherein the engagement of the first alignment features and the second alignment features ensures horizontal alignment.

56. A method according to any of claims 46-55 wherein a photonic device comprises a passive optical component, such as an optical waveguide, such as an optical fibre or a planar waveguide.

57. A method according to any of claims 46-55, wherein a photonic device comprises an optoelectronic device, such as a laser diode or an LED.

58. A method according to any of claims 46-55, wherein a photonic device comprises an active waveguide component, such as an optical amplifier, such as a fibre amplifier.

59. A method of aligning a plurality of photonic devices, said method comprising the steps of:

- providing a substrate having a plurality of groups of first alignment features disposed thereon,

- providing a first photonic device, said first photonic device comprising a light input or output port and a bottom surface having one or more second alignment features disposed thereon, said first photonic device being positioned on top of a first group of the first alignment features,

- providing a second photonic device, said second photonic device comprising a light input or output port and a bottom surface having one or more second

alignment features disposed thereon, said second photonic device being positioned on top of a second group of the first alignment features so as to align the light input or output port of the first photonic device with the light input or output port of the second photonic device, wherein

the second alignment features of the first and second photonic device are arranged so as to at least partly engage outer side walls of the first and second group of the first alignment features.

60. A method according to claim 59, wherein the light input or output ports of the photonic devices have predetermined orientation(s) and height(s) with respect to the substrate.

61. A method according to claim 59 or 60, wherein the first photonic device comprises a light input port and the second photonic device comprises a light output port, and the photonic devices are positioned so as to align the light input port of the first photonic device with the light output port of the second photonic device.

62. A method according to claim 59 or 60, wherein the first photonic device and the second photonic device both have a light output port, and wherein the photonic devices are positioned so as to align the two light output ports along two parallel optical paths.

63. A method according to any of claims 59-62, wherein the second alignment features of the photonic devices comprise one or more solder stripes.

64. A method according to claim 63, wherein at least two solder stripes are arranged on the bottom of a photonic device.

65. A method according to any of claims 59-64, wherein at least one alignment features of the plurality of groups of first alignment features comprises a tapered part.

66. A method according to any of claims 59-65, wherein the engagement of the first alignment features and the second alignment features ensures horizontal alignment.

67. A method according to any of claims 59-66, wherein the height of the first alignment features is adjusted so as to obtain vertical alignment.

68. A method according to any of claims 59-67 wherein the first and second photonic device comprises passive optical components, such as optical waveguides, such as optical fibres or planar waveguides.

69. A method according to any of claims 59-67, wherein the first and second photonic device comprises optoelectronic devices, such as laser diodes or LEDs.

70. A method according to any of claims 59-67, wherein the first and second photonic device comprises active waveguide components, such as optical amplifiers, such as fibre amplifiers.

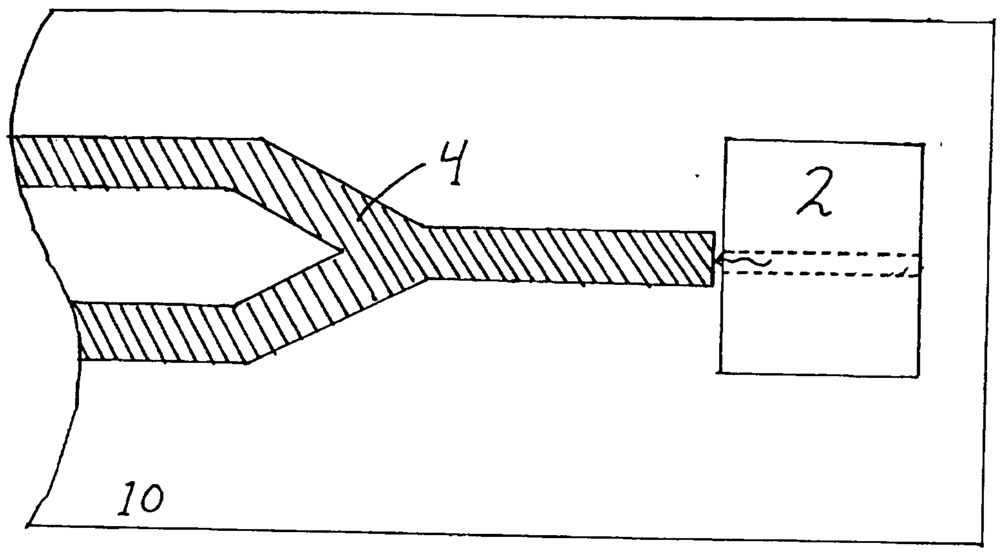

Fig. 1

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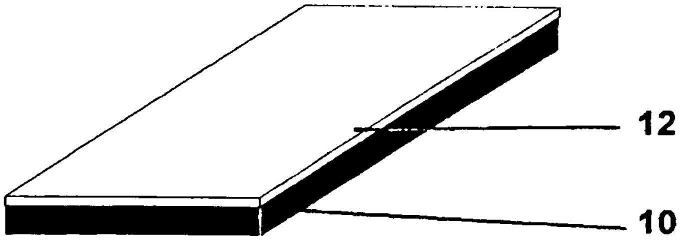

Fig. 2

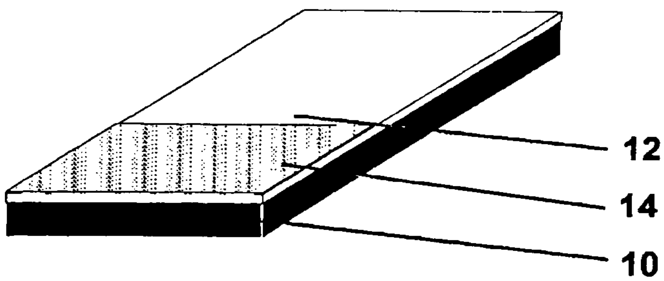

Fig. 3

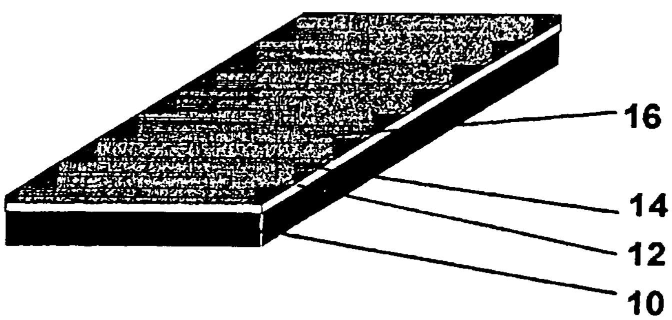

Fig. 4

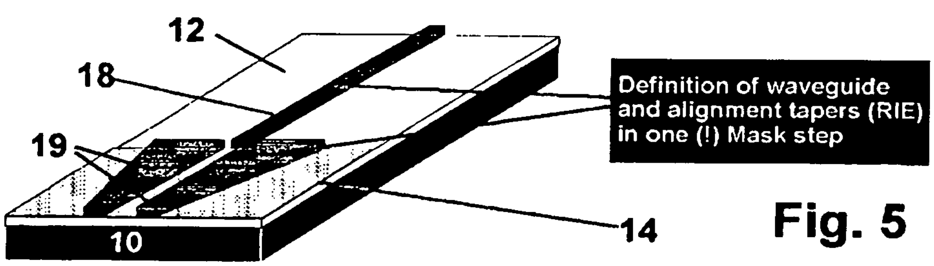

Fig. 5

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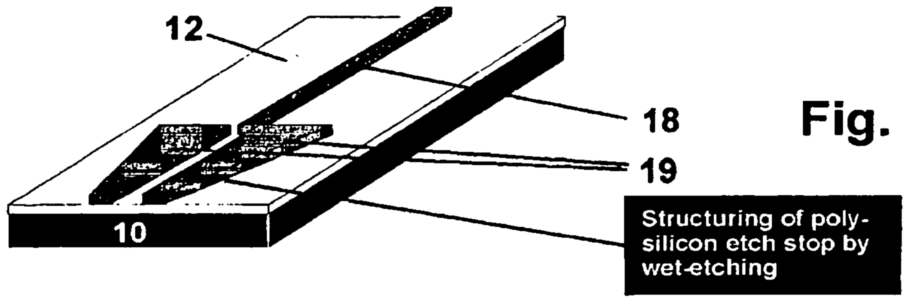

Fig. 6

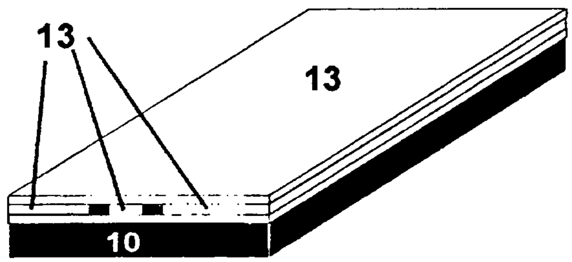

Fig. 7

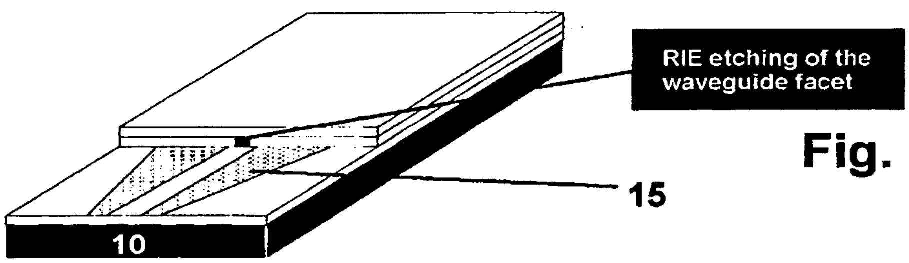

Fig. 8

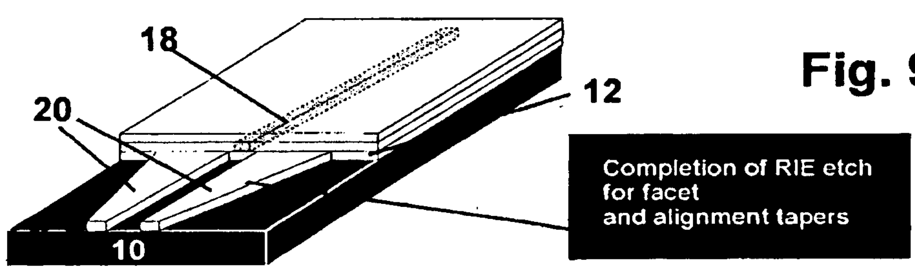

Fig. 9

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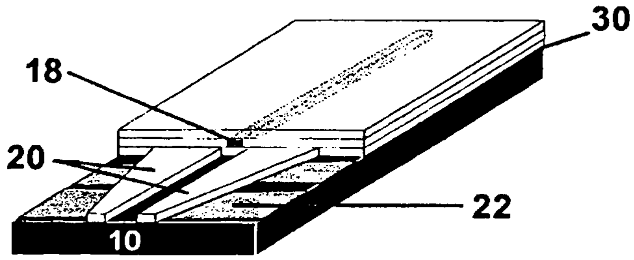

Fig. 10

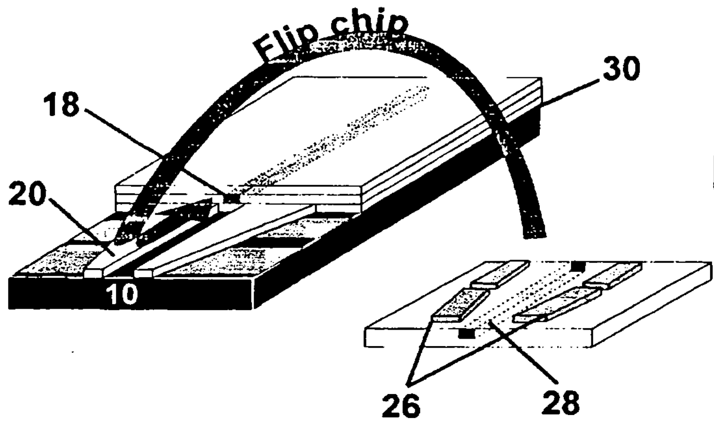

Fig. 11

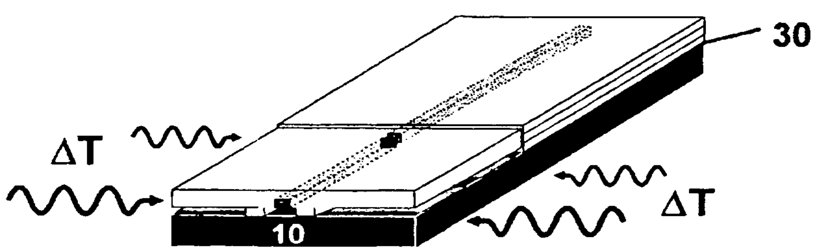

Fig. 12

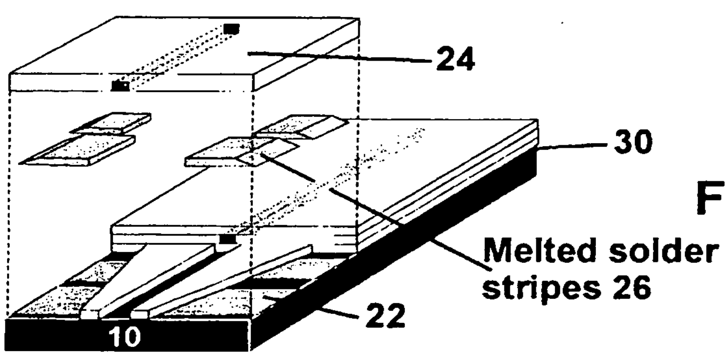

Fig. 13

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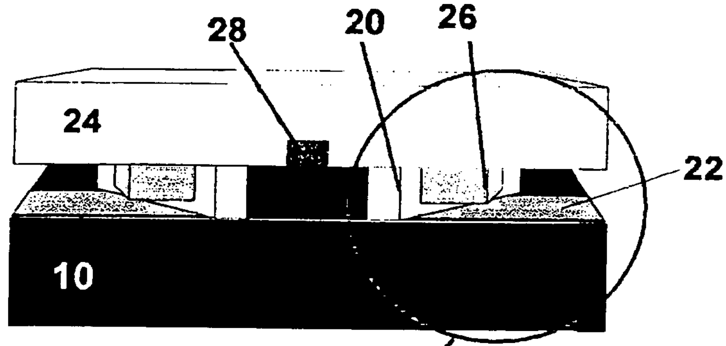
Fig. 14



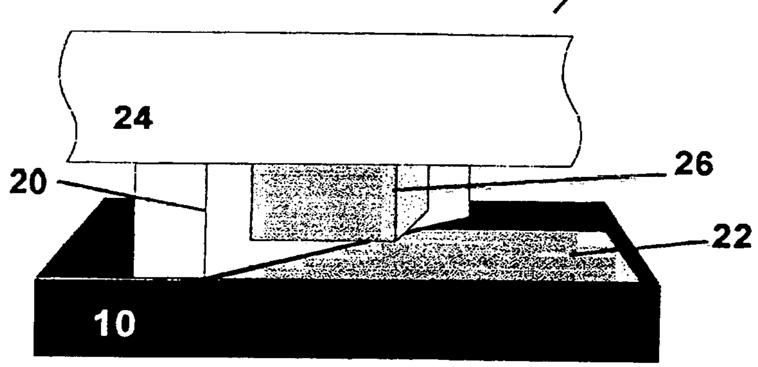
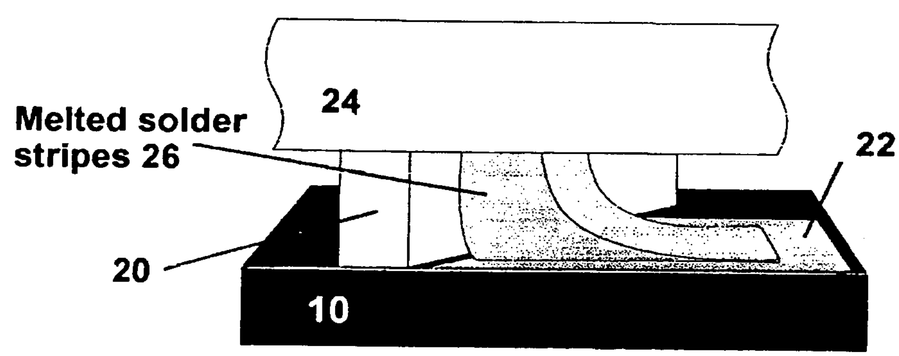


Fig. 15

Fig. 16



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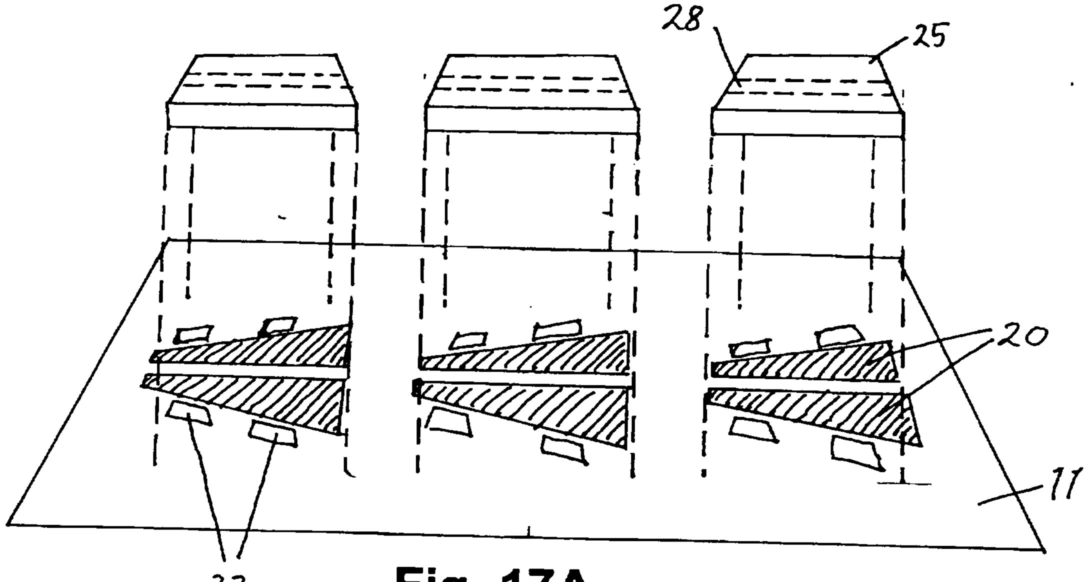

Fig. 17A

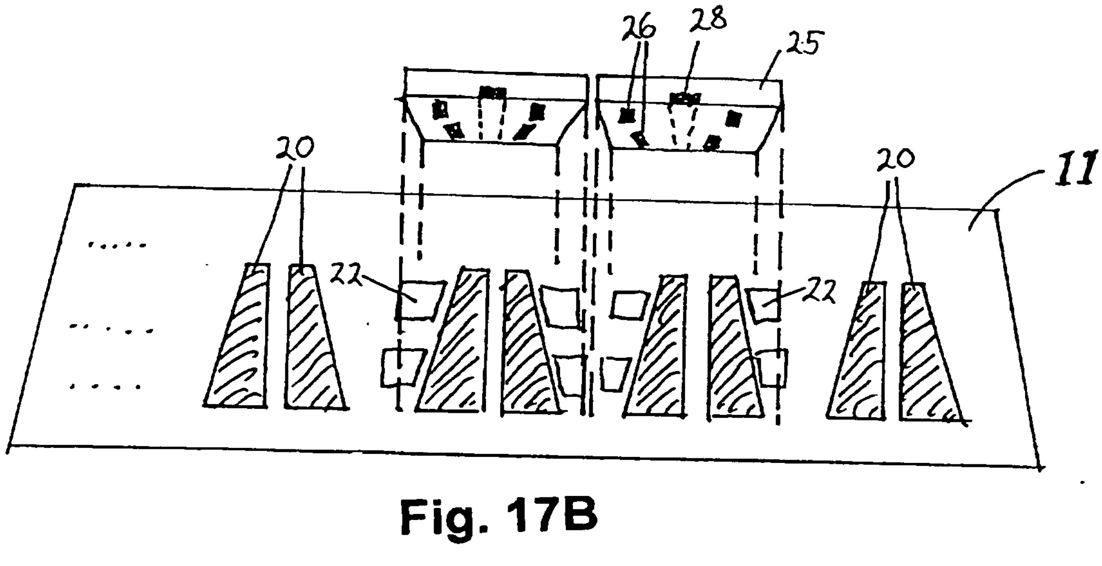

Fig. 17B

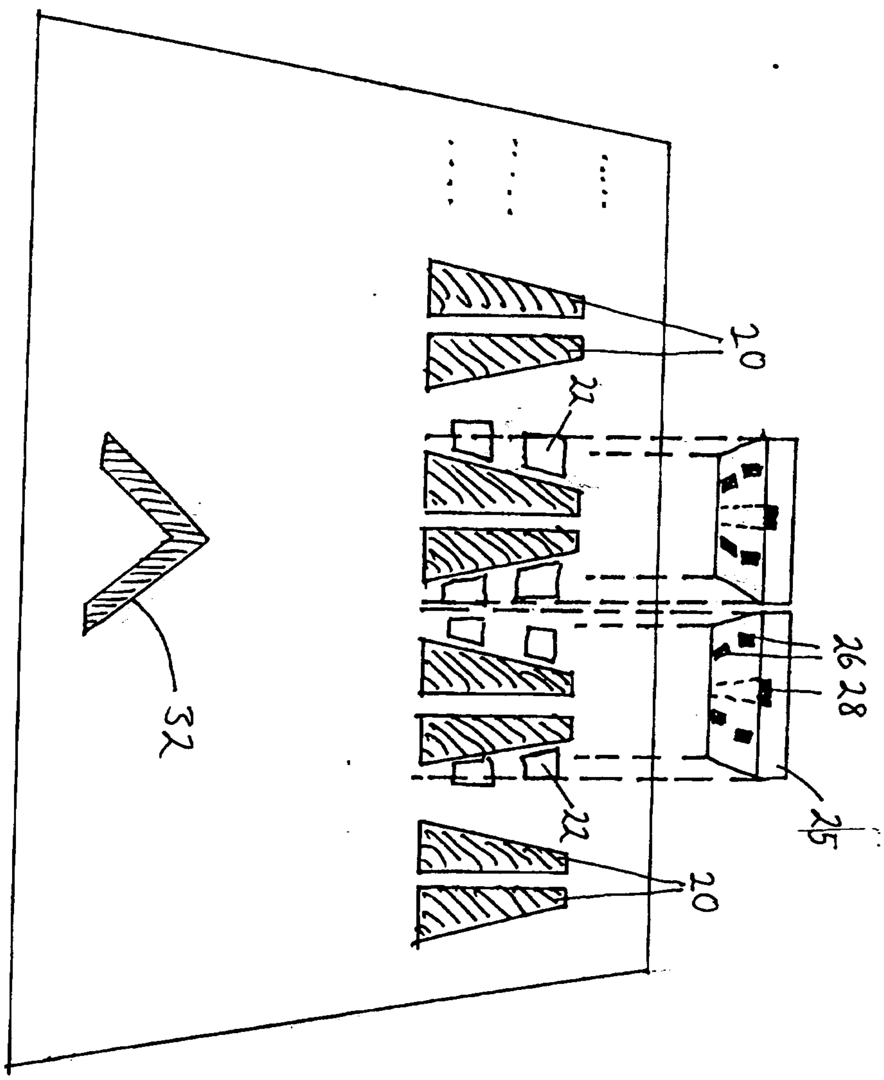

Fig. 18